Measuring the Flow through the Kerama Gap

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BACKGROUND

The principal flows in and out of the East China Sea (ECS) are through channels penetrating the Ryukyu Ridge (Figure 1). Since ~20 Sv of Kuroshio mean flow enters and exits through two of these channels, they are especially well known: the East Taiwan Channel (sill depth 775 m) at the ridge's southwestern end, and the Tokara Strait (sill depth 690 m) near its northeastern end [*Choi et al.*, 2002]. But the deepest channel connecting the ECS to the surrounding ocean is near the ridge mid-point; it is the Kerama Gap, about 50 km wide with sill depth 1050 m [*Choi et al.*, 2002]—see Figure 1.

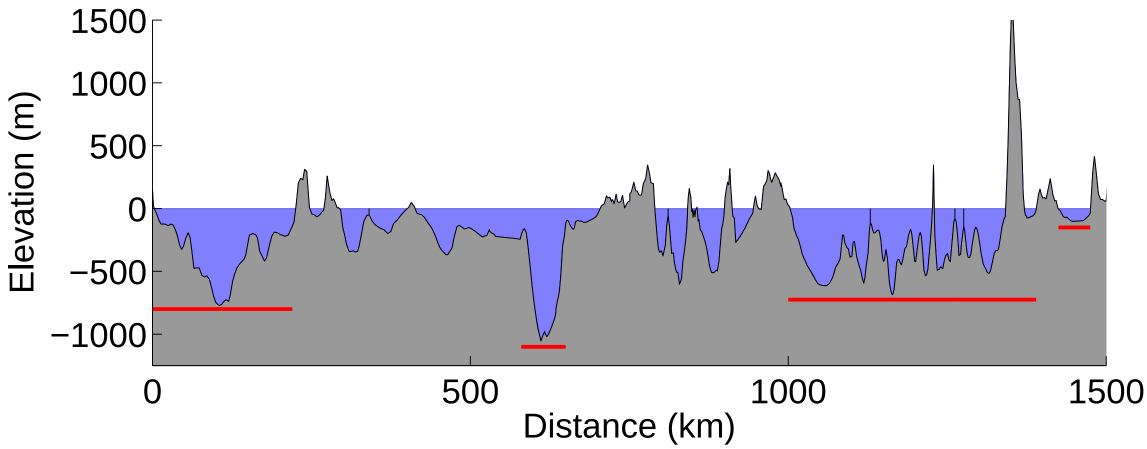

Figure 1. The Ryukyu ridgeline, from Taiwan (on the left) to Kyushu, Japan (on the right). The island of Okinawa is at Distance = 700-800 km, just to the right (i.e., northeast) of the Kerama Gap.

From previous studies, little is reliably known about the flow through the Kerama Gap. Mean-flow estimates from measurements and models range from 0.9 Sv out of the ECS to 7.2 Sv into it. Knowledge of the flow variability is even more uncertain, but there is evidence of transport variations with magnitude a few Sverdrups, caused by impingement of Philippine Sea eddies from the east, at intervals of a few months [*Andres et al*., 2008a].

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Our main purpose in this project is to make a reliable determination of the varying flow through the Kerama Gap.

LONG-TERM GOAL

To measure and understand the time-varying structure and transport of flow between the Pacific Ocean and the ECS through the Kerama Gap, on scales from a few hours to more than a year.

OBJECTIVES

On time scales ranging from two days to two years, our main objectives are to measure the variable flow through the Kerama Gap and to test the following three hypotheses:

(1) increase in transport through the Kerama Gap is associated with (a) an increase in ECS-Kuroshio transport across the PN-line, north of Okinawa, and (b) a decrease in Ryukyu Current transport east of Okinawa about two months earlier;

(2) the arrival of anticyclonic (cyclonic) eddies at the eastern side of the Kerama Gap is associated with an increase (decrease) of transport through the Gap;

(3) variations in wind stress over the local region cause variation in the flow through the Kerama Gap.

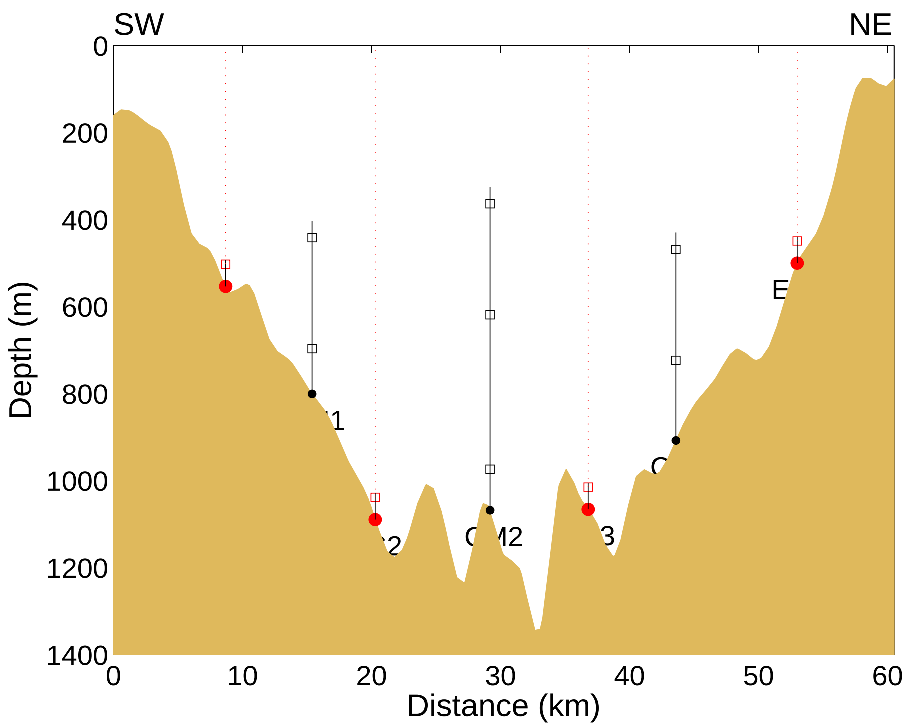

Figure 2. Cross-section diagram of the Kerama Gap array. Four CPIESs are shown as solid red dots (open red squares immediately above represent the current sensors 50 m above the sea floor). Seven CMs on three moorings are shown as black open squares. Topography is from measurements taken on the June 2009 cruise. Note: this section across the Kerama Gap is slightly northwest of the sill, hence the maximum depth at the section is greater than the sill depth (1050 m).

APPROACH

Our plan was to deploy for two years, in conjunction with our Japanese colleague, Dr. Hirohiko Nakamura of Kagoshima University, an array of Current-and-Pressure-sensor-equipped Inverted Echo Sounder (CPIES) instruments and current-meter (CM) moorings across the Kerama Gap. A cross-section of the Kerama Gap showing instruments positions is shown in Figure 2.

WORK COMPLETED

In June 2009, from the Japanese Training Vessel (*T/V*) *Kagoshima-maru*, we, together with Dr. Nakamura and his team, successfully deployed our array of CPIES and CM moorings (Figures 2 & 3) and obtained hydrographic profiles at each site.

In spring 2010, the shallowest current meter (365-m depth on the central CM mooring), together with its floatation, was found by a fisherman near the Tokara Strait drifting on the surface. It appeared to have been severed from the mooring either by trawling or by fish-bite. This occurred on February 9, 2010, but thanks to the Japanese fisherman who retrieved the instrument, we obtained good data up to this time of severance.

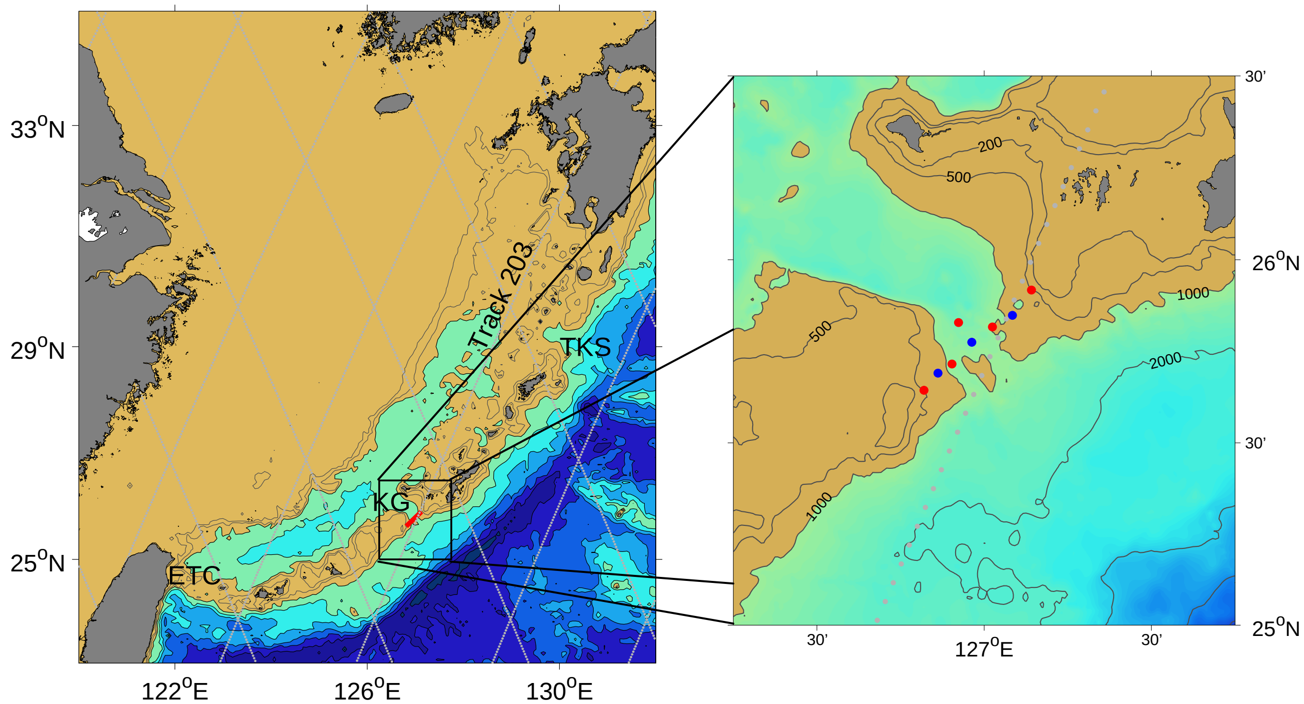

Figure 3. Left panel: East China Sea (ECS) region; ETC = East Taiwan Channel, KG = Kerama Gap, TKS = Tokara Strait; Jason-1 altimetry tracks shown as gray lines; red bar shows position of the deployed array. Right panel: Enlargement of Kerama Gap region showing the deployed array: red dots are CPIES moorings, blue dots are CM moorings. The array is along a line across the Kerama Gap, except that one CPIES instrument near the center of the Gap is about 10 km northwest of this line. Depth contours are at 200, 500, 1000, 2000, 3000 and 4000 m.

In June 2010, using the *T/V Kagoshima-maru* once again, we visited the Kerama Gap region to recover and redeploy the CM moorings, acoustically telemeter the CPIES data, and collect additional hydrographic profiles. All three CM moorings were recovered and good-quality data were recorded in all the CM instruments on the moorings. But there were problems with the CPIES components of the array: (1) intermittent multipath echoes prevented reliable interpretation of the telemetered data from the two shallow CPIES instruments (ES1, ES4), and (2) the three deep CPIES instruments (ES2, ES3, ES5) all suffered cable leaks from apparent fish-bites.

While we were able to determine, from the telemetered CPIES data at the ES1 and ES4 sites, that the instruments appeared to be working correctly, the intermittent multipath echoes resulting from the shallowness (~500 m) of the sites prevented us from obtaining unambiguous time series of the measurements from the telemetered data. Nevertheless, we expect to obtain high-quality time series from these two CPIES instruments when we recover them in June 2011.

Because the telemetered CPIES data from the ES2 and ES3 sites showed serious problems, we decided to recover all three CPIES instruments from the deep (~1000 m) CPIES sites (ES2, ES3 and ES5). We were able to extract acoustic-travel-time, pressure and temperature data from these instruments, but the cables connecting to the current sensors on all three instruments were heavily damaged along their lengths by what appeared to be fish bites. As a result, current measurements were of limited duration at ES2 and ES3, and the cable damage resulted in failure of all measurements at ES2 after 5 months of deployment.

Furthermore, the pressure records from these three instruments showed many sudden pressure increases at times of strong currents (>60 cm/s), indicating movement of the instruments by these currents.

We redeployed one instrument as a PIES (i.e., without current sensor) at ES2, and deployed a spare CPIES (which we had brought) at ES3. The entire Kerama Gap array will be recovered in June 2011 and we will then analyze the full data set.

RESULTS

The time series of (sub-tidal) currents from the CM components of the array are shown in Figure 4. The means and standard-deviation ellipses of these currents are shown in Figure 5.

Mean currents through the Kerama Gap were mainly northward into the ECS, except at the CM1 deeper level where the flow was weak and southeastward. Strongest mean currents were found on the northeast side of the Gap, where the deeper (725 m) mean (12.0 cm/s) exceeded the shallower (470 m) mean (10.1 cm/s). For the 8-month period during which we have current data from all the current meters, we determined that transport below 500 m depth into the ECS through the Kerama Gap had a mean value of 1.2 Sv, while the instantaneous (sub-tidal) values varied between a minimum of −1.6 Sv and a maximum of 4.3 Sv.

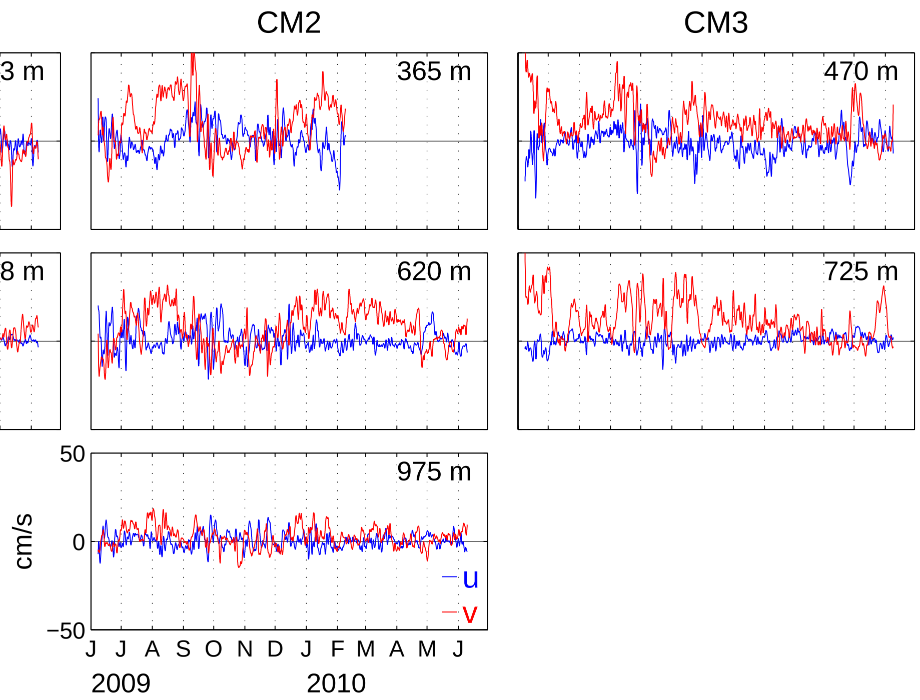

Figure 4. Year-long time series of eastward (u) and northward (v) current components measured at the three CM mooring sites. The record from the uppermost instrument at CM2 ends after 8 months because the instrument was severed from the mooring (see text).

Next year, when we recover the two shallow CPIES instruments, we will be able to use the Gravest Empirical Mode technique to obtain the time-varying transport through the upper 500 m, and hence obtain a two-year time series of the full-water-column transport through the Kerama Gap.

IMPACT/APPLICATIONS

Because flows through the Kerama Gap add to or subtract from the measured Kuroshio flow in the ECS north of Okinawa [*Andres et al*., 2008a], the results from this study should lead to advances in our understanding of western-boundary-current dynamics.

Recently it has been shown that Kuroshio transport in the ECS is correlated with the Pacific Decadal Oscillation (PDO) index [*Andres et al*., 2009]. If, through this two-year measurement of the Kerama Gap transport, we are able to find a suitable long-term proxy (e.g., sea-level differences measured with tide gauges or satellite altimeters), we will determine whether there is a similar PDO-related transport in flow through the Kerama Gap.

RELATED PROJECTS

The University of Rhode Island was supported by ONR to deploy an array of IESs in the Okinawa Trough near the PN-line in a project titled, "Variability of the Kuroshio in the East China Sea, and its Relationship to the Ryukyu Current." These instruments recorded the main part of the Kuroshio transport in the ECS. The array was deployed in December 2002 and recovered in November 2004, thus providing spatiotemporal structure of the Kuroshio for a two-year time period. The results of this study are to be found in *Andres et al*. [2008a,b] and *Andres et al*. [2009].

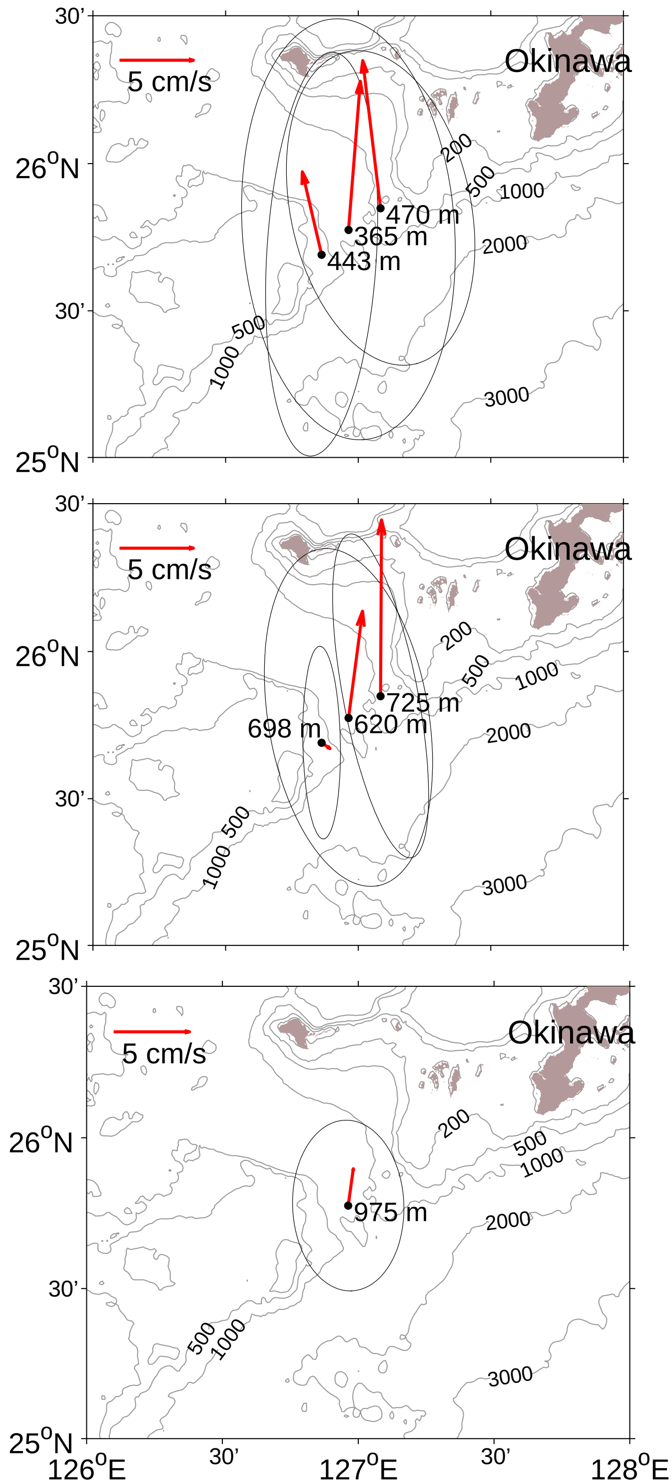

Figure 5. Mean currents and standard-deviation ellipses measured at upper, middle and deep levels by the three CM moorings. Mean flows are northward (i.e., into the ECS) and variability is comparable to or stronger than the mean in each case. Values are based on the available data for each current meter, i.e., June 2009 – June 2010, except June 2009 – February 2010 at 365 m depth on mooring CM2.

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